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(71) Applicant: Nippon Sheet Glass Co., Ltd.
Osaka-shi, Osaka 541-8559 (JP)

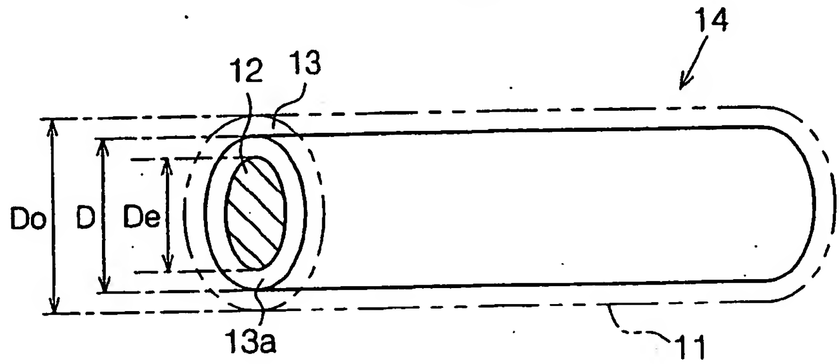
(72) Inventors:
- Ishikawa, Masatake
Osaka-shi, Osaka 541-8559 (JP)
- Koshi, Hiroshi
Osaka-shi, Osaka 541-8559 (JP)
- Ookawa, Kazuya
Osaka-shi, Osaka 541-8559 (JP)
- Taniguchi, Satoshi
Osaka-shi, Osaka 541-8559 (JP)

(74) Representative: Maiwald Patentanwalts GmbH
Achenbachstrasse 43
40237 Düsseldorf (DE)

(54) Refractive index distribution lens, production method thereof, and lens array

(57) A compact refractive index distribution lens that can be manufactured without decreasing the amount of incident light. The refractive index distribution lens (14) includes a lens body radially distributing refractive indexes. The lens body has a cross sectional outline formed by removing at least part of a peripheral portion (13) of a cylindrical original lens body (11).

Fig.1



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Description

[0001] The present invention relates to a refractive index distribution lens, a method for manufacturing a refractive index distribution lens, and a lens array.

[0002] A refractive index distribution lens is manufactured by performing a treatment, such as ion exchange, on a cylindrical piece of glass. This distributes refractive indexes from the central portion of the lens to the peripheral portion of the lens. The refractive indexes at the peripheral portion of the lens normally are not included in the intended refractive index distribution range. Thus, the peripheral portion of the lens cannot be used. For example, referring to Fig. 27, a refractive index distribution lens 11 has an effective portion 12. The effective portion 12 is located in the center of the refractive index distribution lens 11 and has a diameter, which is denoted by De. Aberrations are tolerated in the effective portion 12. A peripheral portion 13 is defined around the effective portion 12. The refractive indexes distributed in the peripheral portion 13 are not included in the intended range. Accordingly, the diameter Do of the refractive index distribution lens 11 is determined by adding a value obtained by multiplying the width of the peripheral portion by two to the effective diameter De of the effective portion 12. Since the refractive indexes distributed in the peripheral portion 13 are not included in the tolerable range, the focal point of the light that passes through the peripheral portion 13 differs from that of the light that passes through the effective portion 12. This produces a large aberration in the lens as shown by Fig. 28.

[0003] The conventional refractive index distribution lens has a diameter that is significantly greater than the effective diameter of the effective portion 12, which is the portion actually functioning as a lens. Thus, when a plurality of refractive index distribution lens are arranged to form a lens array 21, as shown in Fig. 29, the lenses increases the size of the lens array 21 and the pitch between effective portions 12. This lowers resolution. In the example shown in Fig. 29, the refractive index distribution lenses 11 are arranged in V-shaped grooves of a substrate 22. To reduce the size of the lens array 21, the diameter Do of the lens may be decreased. However, this would decrease the area of the effective portion and decrease the amount of the light that enters the effective portion 12.

[0004] A planar micro-lens array has been proposed to decrease the size of a lens array. In one type of lens array, the refractive index distribution is such that the refractive index differs at different depths in a substrate. In another type of lens array, the surface of a lens array is etched to form pits, and resins having different refractive indexes are filled in the pits. However, satisfactory lens characteristics cannot be obtained when such lens arrays are used to connect optical fibers with optical devices.

[0005] It is an object of the present invention to provide a smaller refractive index distribution lens without decreasing the amount of light that enters its effective portion.

[0006] To achieve the above object, the present invention provides a refractive index distribution lens including a lens body radially distributing refractive indexes. The lens body has a cross sectional outline formed by removing at least part of a peripheral portion of a cylindrical original lens body.

[0007] In an embodiment of the present invention, a method for manufacturing a refractive index distribution lens is provided. The method includes preparing a cylindrical original lens body and forming a lens body having a predetermined cross sectional outline by removing at least part of a peripheral portion of the original lens body.

[0008] In another embodiment of the present invention, a lens array including at least a row of a plurality of refractive index distribution lenses is provided. Each of the refractive index distribution lenses includes a lens body radially distributing refractive indexes. The lens body has a cross sectional outline formed by removing at least part of a peripheral portion of a cylindrical original lens body.

[0009] A detailed description of the present invention will now be given, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a perspective view showing a refractive index distribution lens according to a first embodiment of the present invention;

Fig. 2 is an explanatory diagram illustrating the aberration of the refractive index distribution lens of Fig. 1;

Fig. 3 is a perspective view showing a further refractive index distribution lens according to the first embodiment of the present invention;

Fig. 4 is a perspective view showing a lens array including the refractive index distribution lens of Fig. 1;

Fig. 5 is a perspective view showing a lens array including the refractive index distribution lens of Fig. 3;

Fig. 6 is a schematic cross-sectional view illustrating a procedure for machining a refractive index distribution lens in a second embodiment of the present Invention;

Fig. 7 is a front view showing the refractive index distribution lens of the second embodiment;

Fig. 8 is a front view showing a lens array including the refractive index distribution lens of Fig. 7;

Fig. 9 is a perspective view showing a two-dimensional array including the refractive index distribution lens of Fig. 7;

Fig. 10 is a front view showing a refractive index distribution lens according to a third embodiment of the present invention;

Fig. 11 is a front view showing a lens array including the refractive index distribution lens of Fig. 10;

Fig. 12 is a perspective view showing a two-stage lens array including the refractive index distribution lens of Fig. 7;

Fig. 13 is a perspective view showing a two-dimensional array including the refractive index distribution lens of Fig. 10;

Fig. 14 is a front view showing a refractive index distribution lens according to a fourth embodiment of the present invention;

Fig. 15 is a front view showing a lens array including the refractive index distribution lens of Fig. 14;

Fig. 16 is a perspective view of a two-dimensional array including the refractive index distribution lens of Fig. 14;

Fig. 17 is a front view showing a refractive index distribution lens according to a fifth embodiment of the present Invention;

Fig. 18 is a front view showing a lens array Including the refractive index distribution lens of Fig. 17;

Fig. 19 is a front view showing a further refractive index distribution lens according to the fifth embodiment of the present invention;

Fig. 20 is a front view showing a lens array including the refractive index distribution lens of Fig. 19;

Fig. 21 is a front view of a refractive index distribution lens according to a first modification of the fifth embodiment;

Fig. 22 is a front view showing a lens array including the refractive index distribution lens of Fig. 21;

Fig. 23 is a front view of a refractive index distribution lens according to a second modification of the fifth embodiment;

Fig. 24 is a front view showing a lens array including the refractive index distribution lens of Fig. 23;

Fig. 25 is a front view showing a refractive index distribution lens according to the third embodiment of the present invention;

Fig. 26 is a front view showing a two-stage lens array including the refractive index distribution lens of Fig. 1;

Fig. 27 is a perspective view showing a prior art refractive index distribution lens;

Fig. 28 is an explanatory diagram illustrating the aberration of the prior art refractive index distribution lens; and

Fig. 29 is a front view showing a lens array including the prior art refractive index distribution lens.

[0010] In the drawings, like numerals are used for like elements throughout.

[First Embodiment]

[0011] A refractive index distribution lens 14 and a lens array 16 according to a first embodiment of the present invention will now be described with reference to Figs. 1 to 5.

[0012] In Fig. 1, the broken lines show a refractive index distribution lens 11 (original lens), which is manufactured through a normally performed process. The refractive index distribution lens 11 undergoes mechanical or chemical processing to partially remove its peripheral portion 13. The partial removal of the peripheral portion 13 exposes an underlying peripheral portion 13a of the lens 14. When the diameter of the lens 14 prior to the removal of the peripheral portions 13a is Do (refer to Fig. 27), the diameter D of the lens 14 of Fig. 1 subsequent to the removal of the peripheral portions 13a is smaller than Do. It is preferred that the peripheral portion 13 be partially removed so that the ratio between the effective diameter De of an effective portion 12 (indicated by diagonal lines) and the lens diameter D be $0.3 \leqq De/D \leqq 1$. In one example, the peripheral portions of a refractive index distribution lens 11 satisfying the equation of $De/Do=0.4$ are removed to form a refractive index distribution lens 14 satisfying the equation of $De/D=0.9$. Fig. 2 illustrates the aberration when only the effective portion 12 of the refractive index distribution lens 14 is irradiated with light. As apparent from Fig. 2, the aberration is small. The peripheral portion may be removed by performing mechanical processing, or cylindrical grinding. If chemical processing is performed, the refractive index distribution lens 11 is dipped into a hydrofluoric acid solution to partially remove the peripheral portions. The two ends of the lens 11 are then mechanically ground to form the refractive index distribution lens 14. Further, all of the peripheral portions 13 may be removed ($De/D=1$) to form the lens 14. In this case, light enters only the effective portion 12. Thus, the aberration is similar to that shown in Fig. 2.

[0013] As shown in Fig. 3, all of the peripheral portion and part of the effective portion 12 may be removed to form a lens 15. In this case, the effective diameter Df of the lens subsequent to the removal satisfies $Df<De$. Thus, the entire refractive index distribution lens 15 is the effective portion. The aberration of the lens is similar to that illustrated in Fig. 2

[0014] Fig. 4 is a schematic view showing a lens array 16 including a plurality of the refractive index distribution lenses 14, from which the peripheral portions 13 have partially been removed. The lens array 16 is formed by embedding a plurality of the refractive index distribution lenses 14 in a synthetic resin substrate. The effective diameter De of the effective portion 12 in each lens 14 is the same as that of the effective diameter in a conventional lens. However, the diameter D of each lens 14 is smaller than the diameter Do of the conventional lens. This decreases the pitch between the lenses 14, which, in turn, increases the resolution of the lens array 16.

[0015] Fig. 5 is a schematic view showing a lens array 16 including a plurality of the refractive index distribution lenses 15, from which all of the peripheral portions 13 and part of the effective portions 12 have partially been removed. In this case, the diameter of each lens 15 is smaller ($Df<De$) than that of the lens 14. Thus, the lens array 16 is more compact than that of Fig. 4 and has a

higher resolution.

[0016] The refractive index distribution lenses of the first embodiment have the advantages described below.

(1) In the refractive index distribution lens 14, a predetermined amount of part of the peripheral portion 13 is removed from the lens 14, and the effective portion 12 remains intact in the lens 14. Thus, the lens 14 is made more compact without touching the effective portion 12. Further, the area occupied by the effective portion 12 in the refractive index distribution lens 14 is greater than that of a conventional lens having the same lens diameter. Thus, light enters a wider effective portion. In other words, the amount of light entering the effective portion of the lens is increased.

(2) In the refractive index distribution lens 15, part (outer portion) of the effective portion 12 is removed in addition to the peripheral portion 13. Thus, the effective portion occupies the entire lens 15, and the lens 15 is made more compact. Further, light enters an effective portion that is wider than that of a conventional lens having the same lens diameter. In other words, the amount of light entering the effective portion of the lens is increased.

(3) Mechanical processing, such as grinding, or chemical processing, such as etching, is performed to remove the peripheral portion 13. Thus, the amount of removed material may be accurately controlled by measuring the removed amount during the processing. In other words, the lenses 14, 15 may be accurately formed.

(4) The removal of the peripheral portions 13 forms the compact lenses 14, 15. Thus, the pitch of the lenses 14, 15 is small. As a result, the lens array 16 has a high resolution and a large capacity.

(5) In the lens array 16 that includes the refractive index distribution lenses 14, 15, which have the large effective portions 12, the amount of light entering the effective portions 12 is large.

[Second Embodiment]

[0017] A refractive index distribution lens 27 and a lens array 28 according to a second embodiment of the present invention will now be described with reference to Figs. 6 to 9.

[0018] Referring to Fig. 7, the refractive index distribution lens 27 of the second embodiment has the form of a rectangular block. Further, the refractive index distribution lens 27 is formed by machining the refractive index distribution lens 11 to remove part of the peripheral portion 13 from the refractive index distribution lens 11. The cross-section of the rectangular block is such that it corresponds to squares ranging from one circumscribing the effective portion 12 with each side having a length of De to one inscribing the circumference of the lens 11 prior to machining with each side having a length of Dg.

[0019] The manufacturing of the lens 27 will now be described. As shown in Fig. 6, a plurality of the cylindrical refractive index distribution lenses (rod lenses) 11 are arranged on a table 24. Wax 23 is applied to adhere and fix the lenses 11 to the table 24. The peripheral portions 13 of the lenses 11 is ground starting from a plane F that is parallel to the table 24 and tangential to the peripheral surfaces of the lenses 11. A first surface, or one of the four surfaces, of each lens 27 is formed when a predetermined amount d1 is ground. Referring to Fig. 7, the predetermined amount d1 is minimal when the length of each of the four sides of the lens 27 is Dg and maximal when the length of each of the four sides is De. After the grinding is completed, the wax 23 is melted to remove the lenses 11 from the table 24. The lenses 11 are then flipped over and adhered to the table 24 so that the ground surfaces contact the table 24. The predetermined amount d1 is then ground from the peripheral portions 13 on the other side of the ground surfaces in the same manner to form a second surface of each lens 27. Subsequently, the lenses 11 are rearranged on and fixed to the table 24 so that the two ground surfaces are perpendicular to the table 24. The predetermined amount d1 is ground to form a third surface of each lens 27. Then, the lenses 11 are flipped over and fixed to the table 24 to grind the predetermined amount d1 from the remaining peripheral portions 13 and form a fourth surface of each lens 27. This completes the formation of the rectangular block-like refractive index distribution lenses 27.

[0020] Fig. 8 is a schematic view showing the lens array 25 in which a plurality of the refractive index distribution lenses 27 are arranged. The lens array 25 includes a substrate 26 and a plurality of the rectangular block-like refractive index distribution lenses 27, which are arranged on the substrate 26. Since the lenses 27 have flat surfaces, the V-groove substrate 22 used in the prior art lens array 21, which is shown in Fig. 29, is not necessary. Further, since the peripheral portion 13 of each lens 27 is removed, the pitch between the lenses 27 is small. Thus, the lens array 25 has a resolution that is higher than that of the prior art lens array 21 shown in Fig 29.

[0021] Fig. 9 is a schematic view showing a lens array 28 in which a plurality of the refractive index distribution lenses 27 are arranged in a two-dimensional manner. Rows of the refractive index distribution lenses 27 are superimposed on the substrate 26. When the lenses 27 are arranged in a two-dimensional manner, the pitch between the adjacent lenses 27 is relatively small. Thus, the two-dimensional lens array 28 has a high resolution.

[0022] In addition to advantages (1), (3), (4), and (5) of the first embodiment, the refractive index distribution

lens 27 of the second embodiment has the advantages described below.

(6) The lens 27 has the form of a rectangular block. This decreases the pitch between the lenses 27 and increases the resolution in one-dimensional and two-dimensional arrays.

(7) The lens 27 has a flat bottom surface (peripheral surface). Thus the lens array 28 is formed just by placing the lens 27 on the flat substrate 26. In other words, the pitch of the lenses 27 is accurately set without using an expensive V-groove substrate.

[Third Embodiment]

[0023] A refractive index distribution lens 30 and lens arrays 29, 31, 32 according to a third embodiment of the present invention will now be described with reference to Figs. 10 to 13.

[0024] Referring to Fig. 10, the refractive index distribution lens 30 of the third embodiment has the form of a triangular block. Further, the refractive index distribution lens 30 is formed by machining the refractive index distribution lens 11 to remove part of the peripheral portion 13 from the cylindrical refractive index distribution lens 11. The cross-section of the triangular block is such that it corresponds to a triangle ranging from one circumscribing the effective portion 12 with each side having a length of Te to one inscribing the circumference of the lens 11 prior to machining with each side having a length of Tg.

[0025] Since the lens 30 is manufactured in the same manner as the rectangular block-like lens 27 of the second embodiment, only the differing points will be described. The peripheral portions 13 of a plurality of the refractive index distribution lenses 11, which are arranged on a table, are ground parallel to the table 24. A first surface, or one of the three surfaces, of each lens 30 is formed when a predetermined amount d1 is ground. The predetermined amount d1 is minimal when the length of each of the three sides of the lens 30 is Tg and maximal when the length of each of the three sides is Te. After the grinding is completed, the lenses 11 are removed from the table 24. The lenses 11 are then adhered to the table 24 in a state in which the first surfaces are inclined by 60° relative to the table 24. The predetermined amount d1 is then ground from the peripheral portions 13 to form a second surface of each lens 30. Subsequently, the lenses 11 are rearranged on and fixed to the table 24 so that the first and second surfaces are inclined by 60° relative to the table 24. The predetermined amount d1 is ground to form a third surface of each lens 30. This completes the formation of the triangular block-like refractive index distribution lenses 30.

[0026] Fig. 11 is a schematic view showing the lens array 29, which includes a plurality of the refractive index distribution lenses 30. The triangular block-like refractive index distribution lenses 30 are arranged close to each other on a substrate 26. The lenses 30 have a flat bottom surface. Thus, the V-groove substrate used by the lens array 21 of Fig. 29 is unnecessary. Further, the two-dimensional lens array 31, which has a two-stage structure as shown in Fig. 12, is formed by arranging a plurality of the refractive distribution index lenses 30 between adjacent lenses 30, which have been arranged on the substrate 26.

[0027] Fig. 13 is a schematic view showing the lens array 32, which includes three or more stages (in this case, four stages) of the triangular block-like refractive index distribution lenses 30. In other words, a plurality of the triangular block-like refractive index distribution lenses 30 are superimposed on the substrate 26.

[0028] In addition to advantages (1), (3), (4), (5), and (7) of the first and second embodiments, the refractive index distribution lens 30 and the lens arrays 29, 31, 32 of the third embodiment has the advantage described below.

(8) The pitch of the triangular block-like lenses 30 is smaller than that of the cylindrical lenses 11. Thus, the one-dimensional lens array 29 and the two-dimensional lens arrays 31, 32 have a high resolution.

[Fourth Embodiment]

[0029] A refractive index distribution lens 34 and lens arrays 33, 35 according to a fourth embodiment of the present invention will now be described with reference to Figs. 14 to 16.

[0030] Referring to Fig. 14, the refractive index distribution lens 34 of the fourth embodiment has the form of a hexagonal block. Further, the refractive index distribution lens 34 is formed by machining the refractive index distribution lens 11 to remove part of the peripheral portion 13 from the cylindrical refractive index distribution lens 11. The cross-section of the hexagonal block is such that it corresponds to a hexagon ranging from one circumscribing the effective portion 12 with each side having a length of He to one inscribing the circumference of the lens 11 prior to machining with each side having a length of Hg.

[0031] Since the lens 34 is manufactured in the same manner as the rectangular block-like lens 27 of the second embodiment, only the differing points will be described. The peripheral portions 13 of a plurality of the refractive index distribution lenses 11 are arranged on a table 24 and ground parallel to the table 24. A first surface, or one of the six surfaces, of each lens 34 is formed when a predetermined amount d1 is ground. The predetermined amount d1 is minimal when the length of each of the six sides of the lens 34 is Hg and maximal when the length of each of the six sides is He. After the grinding is completed, the lenses 11 are removed from the table 24. Subsequently, the lenses 11 are ground to

sequentially form second to sixth surfaces. Thus, the lenses 11 undergo grinding for a total of six times. This completes the formation of the hexagonal block-like refractive index distribution lenses 34.

[0032] Fig. 15 is a schematic view showing the lens array, which includes a plurality of the refractive index distribution lenses 34. The hexagonal block-like refractive index distribution lenses 34 are arranged on a substrate 26 in a state contacting side surfaces of the adjacent lenses 34. Since the lenses 34 have flat side surfaces, the side surfaces are easily connected with each other. Fig. 16 is a schematic view showing the lens array 35, which includes a plurality of the refractive index distribution lenses 34 accumulated so as to have a dense structure.

[0033] In addition to advantages (1), (3), (4), (5), and (7) of the first and second embodiments, the refractive index distribution lens 34 and the lens arrays 33, 35 of the fourth embodiment have the advantage described below.

(9) The hexagonal lens 34 is optimal for forming the two-dimensional lens array 35, which has a dense structure.

[Fifth Embodiment]

[0034] Refractive index distribution lens 36, 39 and lens arrays 38, 40 according to a fifth embodiment of the present invention will now be described with reference to Figs. 17 to 19.

[0035] As shown in Fig. 17, the refractive index distribution lens 36 of the fifth embodiment has two parallel flat side surfaces 37a. The lens 36 is formed by machining the peripheral portion 13 to remove two side portions 37, which are located on opposite sides of the effective portion 12, from a lens 11. Each of the side surfaces 37a is formed by grinding the side portions 37 until reaching the effective portion 12. The grinding is performed in the same manner as in the second embodiment.

[0036] Fig. 18 is a schematic view showing the lens array 38, which includes a plurality of the lenses 36. The lens array 38 includes a substrate 22. V-shaped grooves 22a extend along the surface of the substrate 22. The refractive index distribution lenses 36 are each arranged in one of the V-shaped grooves 22a. The V-shaped grooves 22a are formed by performing anisotropic etching or by dicing the substrate 22 with a diamond blade saw. The distance between adjacent V-shaped grooves 22a is determined by the distance between the two side surfaces 38a of each refractive index distribution lens 36. Two arcuate surfaces extend between the two side surfaces 37a in each refractive index distribution lens 36. Each lens 36 is arranged in the corresponding V-shaped groove 22a with parts of one of its arched surfaces contacting parts of the V-shaped groove 22a. Further, the adjacent lenses 36 are in contact with each other. Due to the closely arranged lenses 36, the lens array 38 has a high resolution.

[0037] As shown in Fig. 19, the refractive index distribution lens 39 has one flat side surface 37b. In this case, as shown in Fig. 20, the lens 39 is arranged on the substrate 22 so that the side surface 37b is perpendicular to the substrate 22. This decreases the pitch between the adjacent lenses 39. Thus, the lens array 40 has a high resolution.

[0038] In addition to advantages (1), (3), (4), and (5) of the first embodiment, the refractive index distribution lens 36 and the lens arrays 38 of the fifth embodiment have the advantage described below.

(10) The lens 39 is arranged so that its arcuate surface contacts the V-shaped groove 22a and its side surface 37b is perpendicular to the substrate 22. Thus, the lens array 40 has a high resolution.

[0039] A first modification and a second modification of the lens 39 of the fifth embodiment will now be described with reference to Figs. 21 to 24.

(First Modification)

[0040] To form a lens array that employs V-shaped grooves 22a of a substrate 22, a lens 41 having a cornered portion, as shown in Fig. 21, is fitted in each of the V-shaped grooves 22a. The cornered portion of the lens 41 is defined by two side surfaces 41a, which are formed by grinding a cylindrical lens. The angle θ between the two side surfaces 41a of the cornered portion is 90°. As shown in Fig. 22, the cornered portion is fitted in the corresponding V-shaped groove 22a, the surfaces of which intersect at 90°. A plurality of the lenses 41 is arranged on the substrate 22 in the same manner to form the lens array 42.

(Second Modification)

[0041] Referring to Fig. 23, a refractive index distribution lens 43 has a cornered portion defined by two side surfaces 43a, which are formed by grinding a cylindrical lens until reaching the effective portion 12. The angle ø between the two side surfaces 43a of the cornered portion is 60°. As shown in Fig. 24, the lens 43 is arranged on a substrate 22 so that the cornered portion is fitted in a corresponding V-shaped groove 22a, the surfaces of which intersect at 60°. A plurality of the lenses 43 is arranged on the substrate 22 in the same manner to form the lens array 44.

[0042] Fig. 25 shows the triangular block-like refractive index distribution lens 30 of the third embodiment. The angle between the two sides of the triangular block-like refractive index distribution lens 30 is 60°. A plurality of the lens 30 may be fitted in the 60° V-shaped grooves 22a to form a lens array on the substrate 22.

[0043] In addition to advantages (1), (3), (4), and (5) of the first embodiment, the first and second modifica-

tions have the advantage described below.

(11) The refractive index distribution lenses 30, 41, 43 are cornered with an angle corresponding to the V-shaped grooves 22a. Thus, the lenses 30, 41, 43 are easily and accurately attached to the substrate 22.

[0044] It should be apparent to those skilled in the art that the present invention may be embodied in many other specific forms. Particularly, it should be understood that the present invention may be embodied in the following forms.

[0045] The cylindrical refractive index distribution lenses 14 or 15 of the first embodiment may be arranged in the V-shaped grooves 22a, as shown in Fig. 26. Further lenses 14, 15 may be superimposed on the lenses 14, 15, which have been arranged in the V-shaped grooves 22a, to form a lens array 45 having a two-dimensional structure. This facilitates the arrangement of the cylindrical refractive index distribution lens 14, 15.

[0046] The rectangular block-like refractive index distribution lenses 27 of the second embodiment may be arranged in the V-shaped grooves of a substrate to form a lens array. In this case, the angle between the adjacent side surfaces of each lens is 90°. It is thus preferred that the angle of the V-shaped grooves be 90°.

[0047] The hexagonal block-like refractive index distribution lenses 34 of the fourth embodiment may be arranged in the V-shaped grooves of a substrate to form a lens array. In this case, the angle between the adjacent side surfaces of each lens is 120°. It is thus preferred that the angle of the V-shaped grooves be 120°.

[0048] The refractive index distribution lenses 36 or 39 of the fifth embodiment may be arranged on a flat substrate so that their flat surfaces 37a, 37b contact the surface of the substrate to form a lens array. A two-dimensional lens array may also be formed by a arranging a plurality of the lenses 36 on a substrate in this manner. In this case, the height of the refractive index distribution lens 36 is relatively low. Thus, the two-dimensional lens array is relatively low.

[0049] The present examples and embodiments are to be considered as illustrative.

Claims

1. A refractive index distribution lens (14, 15, 27, 30, 34, 36, 39, 41, 43) comprising:

   a lens body radially distributing refractive indexes, **characterized in that** the lens body has a cross sectional outline formed by removing at least part of a peripheral portion (13) of a cylindrical original lens body (11).

2. The lens according to claim 1, **characterized in that** the lens body includes an effective portion (12) having an effective diameter (De) that tolerates aberration, wherein the ratio between the effective diameter and a diameter (D) of the lens body is $0.3 \leqq De/D \leqq 1$.

3. The lens according to claim 2, **characterized in that** the cross sectional outline of the lens body is larger than the effective portion and smaller than a cross sectional outline of the original lens body.

4. The lens according to one of claims 1 to 3, **characterized in that** the lens body has a cross sectional outline larger than or equal to a first size circumscribing the effective portion and smaller than or equal to a second size inscribing a periphery of the original lens body.

5. The lens according to claim 4, **characterized in that** the cross sectional outline is one selected from a triangle, a square, and a hexagon.

6. The lens according to claim 4, **characterized in that** the cross sectional outline includes at least one flat surface and at least one arcuate surface.

7. The lens according to claim 1, **characterized in that** the original lens body includes an effective portion (12) and a peripheral portion (13) surrounding the effective portion, the cross sectional outline of the lens body is formed by removing all of the peripheral portion and part of the effective portion, and an effective diameter (Df) of the effective portion of the lens body is smaller than an effective diameter (De) of the effective portion of the original lens body.

8. A method for manufacturing a refractive index distribution lens, the method comprising preparing a cylindrical original lens body (11), the method **characterized by**

   forming a lens body having a predetermined cross sectional outline by removing at least part of a peripheral portion (13) of the original lens body.

9. The method according to claim 8, **characterized in that** the lens body includes an effective portion (12) having an effective diameter (De) that tolerates aberration, wherein the ratio between the effective diameter and a diameter (D) of the lens body is $0.3 \leqq De/D \leqq 1$.

10. The method according to claim 8, **characterized in that** the predetermined cross sectional outline is larger than the effective portion and smaller than a cross sectional outline of the original lens body.

11. The method according to one of claims 8 to 10, **characterized in that** the lens body has a cross

sectional outline larger than or equal to a first size circumscribing the effective portion and smaller than or equal to a second size inscribing a periphery of the original lens body.

12. The method according to claim 11, **characterized in that** the cross sectional outline is one selected from a triangle, a square, and a hexagon.

13. The method according to claim 11, **characterized in that** the cross sectional outline includes at least one flat surface and at least one arcuate surface.

14. The method according to one of claims 8 to 10, **characterized in that** at least part of the peripheral portion of the original lens body is removed through mechanical processing.

15. The method according to one of claims 8 to 10, **characterized in that** at least part of the peripheral portion of the original lens body is removed through chemical processing.

16. A method for manufacturing a refractive index distribution lens, the method comprising preparing a cylindrical original lens body having an effective portion (12) and a peripheral portion (13) surrounding the effective portion, the method **characterized by**

forming a lens body by removing all of the peripheral portion and part of the effective portion.

17. The method according to claim 16, **characterized in that** at least part of the peripheral portion of the original lens body is removed through mechanical processing.

18. The method according to claim 16, **characterized in that** at least part of the peripheral portion of the original lens body is removed through chemical processing.

19. A lens array (16, 25, 28, 29, 31, 32, 33, 35, 38, 40, 42, 44, 45) comprising:

at least a row of a plurality of refractive index distribution lenses (14, 15, 27, 30, 34, 36, 39, 41, 43), wherein each of the refractive index distribution lenses includes a lens body radially distributing refractive indexes, **characterized in that** the lens body has a cross sectional outline formed by removing at least part of a peripheral portion (13) of a cylindrical original lens body (11).

20. The lens array according to claim 19, **characterized by** a substrate having a plurality of grooves for receiving the plurality of refractive index distribution lenses.

21. The lens array according to one of claim 19 or 20, **characterized in that** the lens body includes an effective portion (12) having an effective diameter (De) that tolerates aberration, wherein the ratio between the effective diameter and a diameter (D) of the lens body is $0.3 \leqq De/D \leqq 1$.

22. The lens array according to claim 21, **characterized in that** the cross sectional outline of the lens body is larger than the effective portion and smaller than a cross sectional outline of the original lens body.

23. The lens array according to one of claims 19 to 22, **characterized in that** the lens body has a cross sectional outline larger than or equal to a first size circumscribing the effective portion and smaller than or equal to a second size inscribing a periphery of the original lens body.

24. The lens array according to claim 23, **characterized in that** the cross sectional outline is one selected from a triangle, a square, and a hexagon.

25. The lens array according to claim 23, **characterized in that** the cross sectional outline includes at least one flat surface and at least one arcuate surface.

26. The lens array according to claim 19, **characterized in that** the original lens body includes an effective portion (12) and a peripheral portion (13) surrounding the effective portion, the cross sectional outline of the lens body is formed by removing all of the peripheral portion and part of the effective portion, and an effective diameter (Df) of the effective portion of the lens body is smaller than an effective diameter (De) of the effective portion of the original lens body.

Fig.1

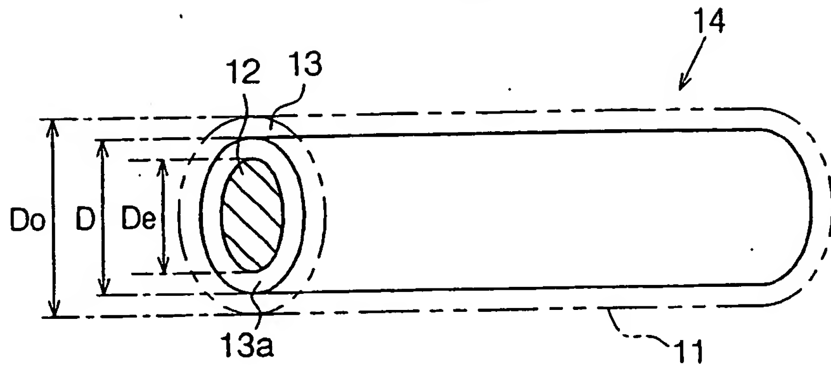


Fig.2

Fig.3

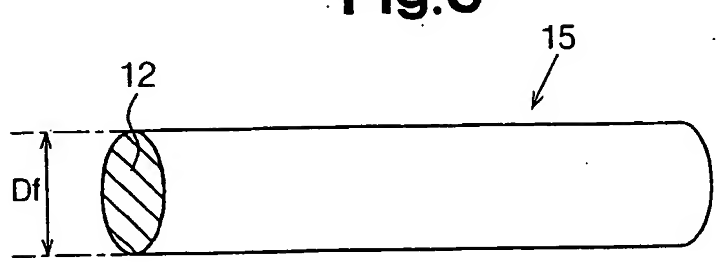


Fig.4

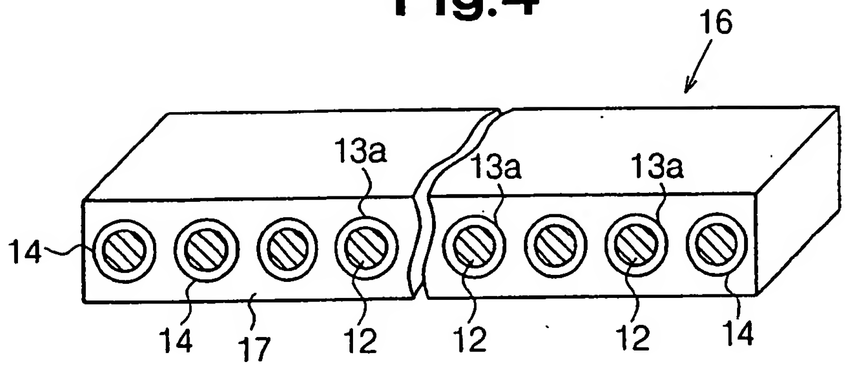


Fig.5

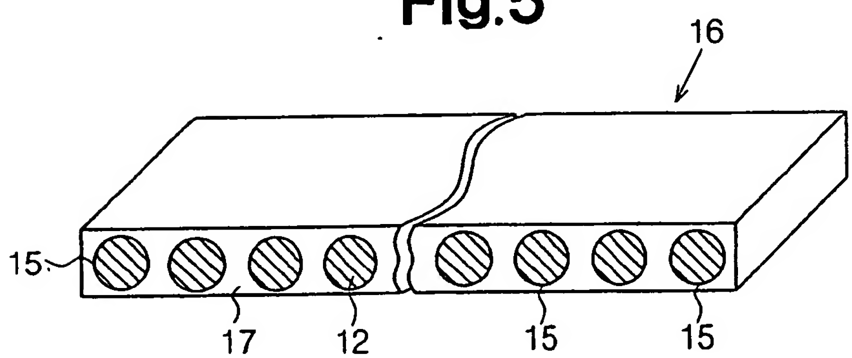


Fig.6

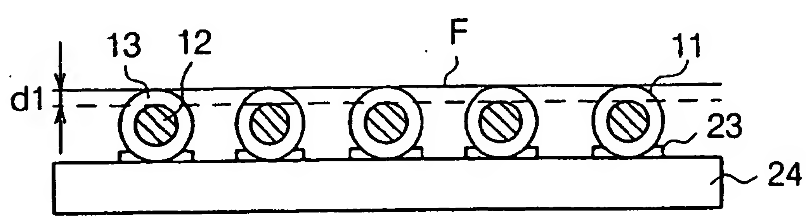


Fig.7

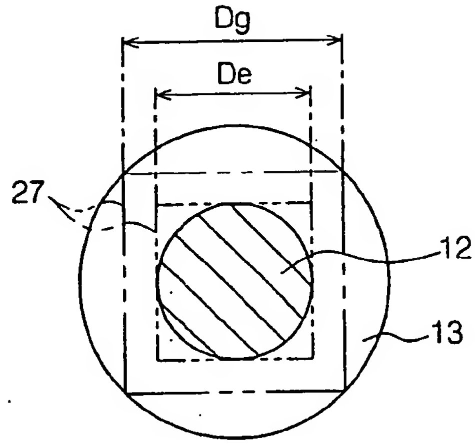


Fig.8

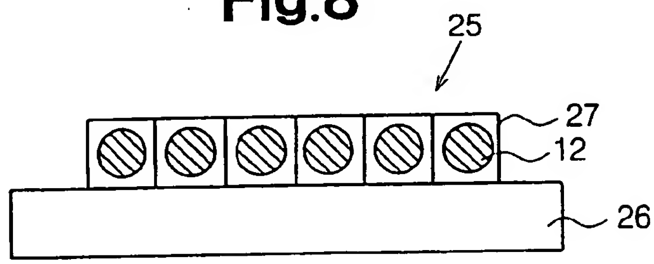


Fig.9

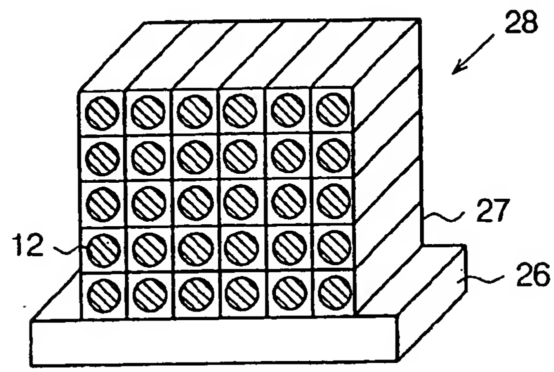


Fig.10

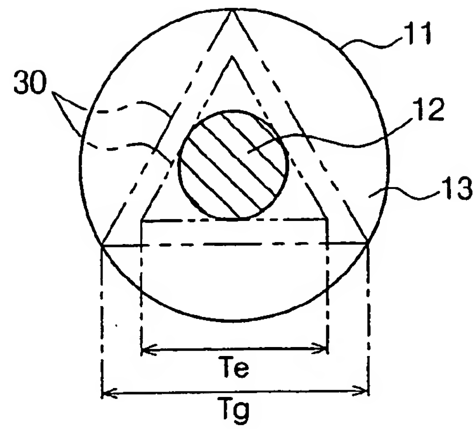


Fig.11

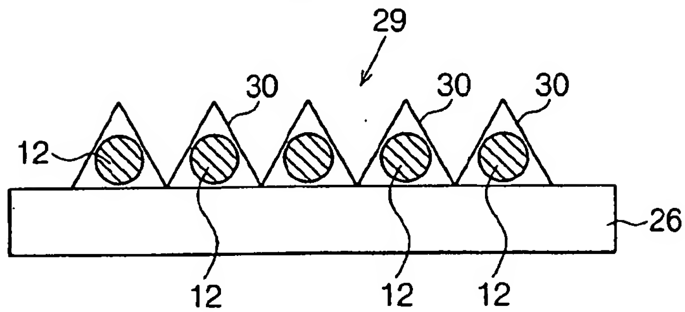


Fig.12

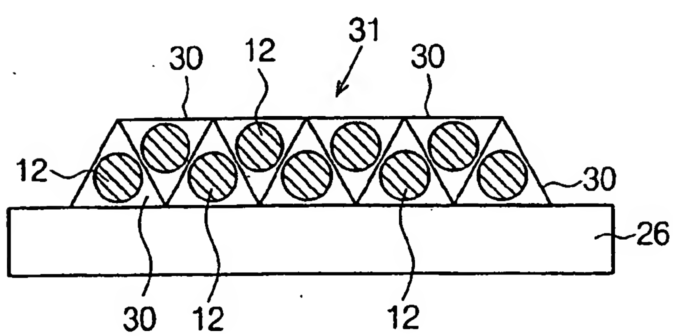


Fig.13

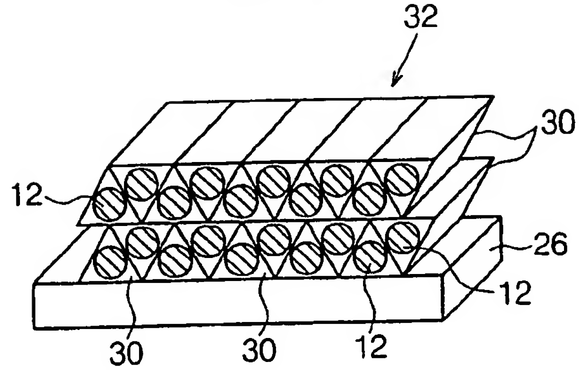


Fig.14

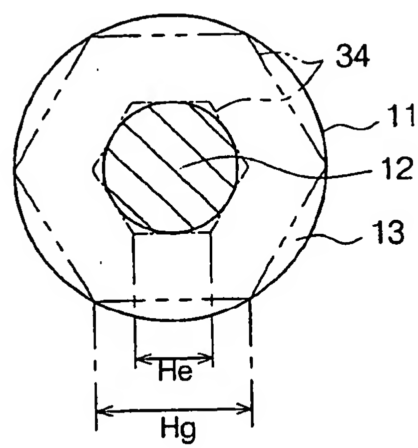


Fig.15

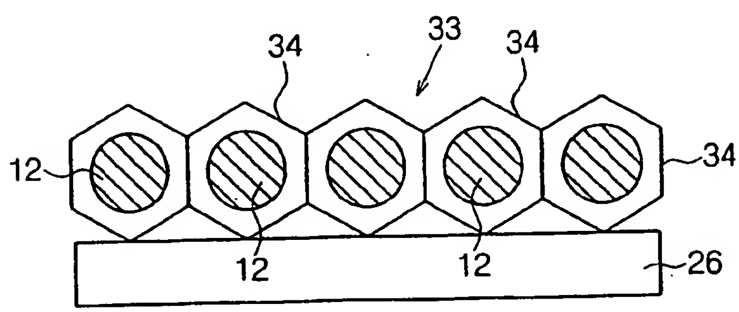


Fig.16

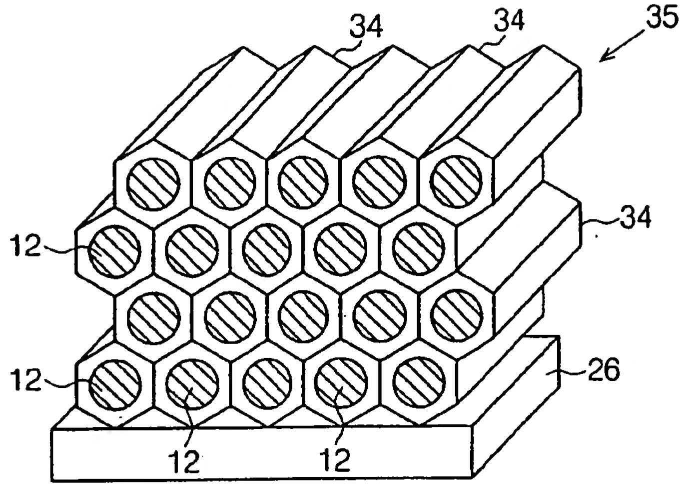


Fig.17

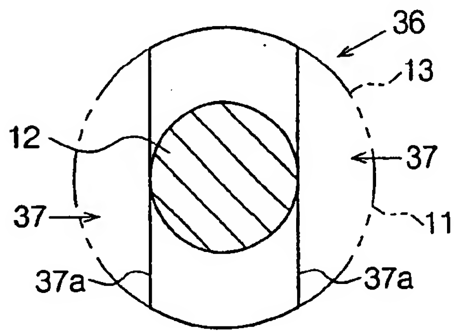


Fig.18

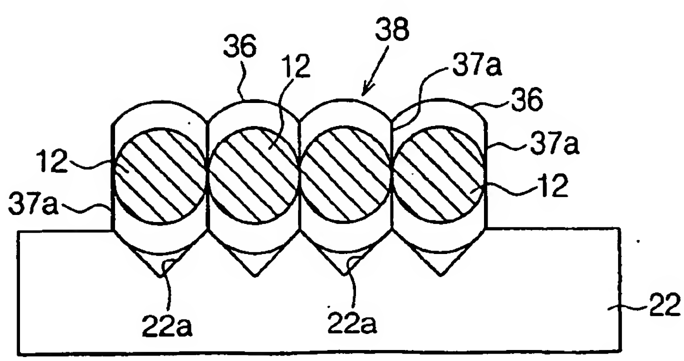


Fig.19

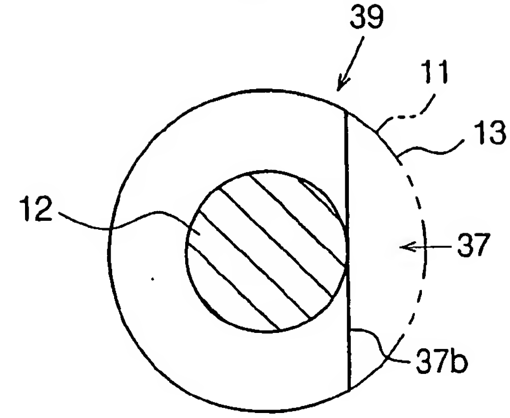


Fig.20

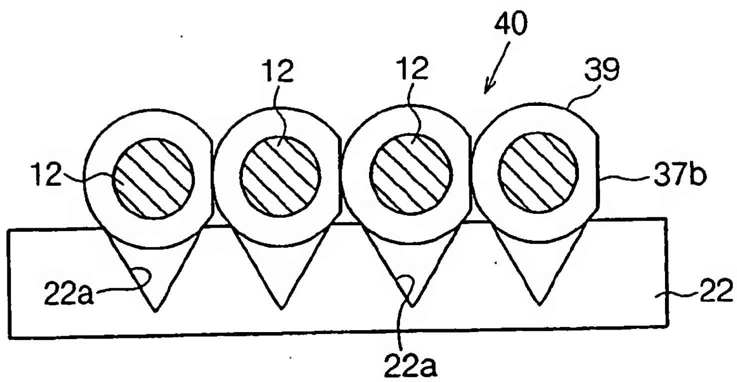


Fig.21

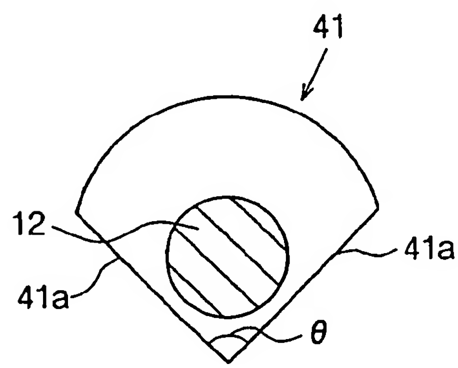


Fig.22

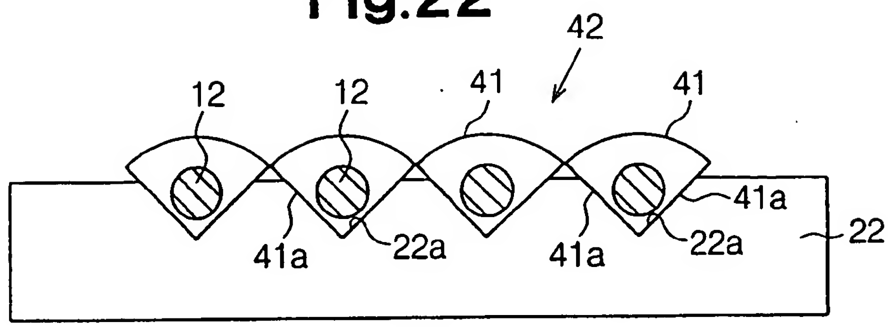


Fig.23

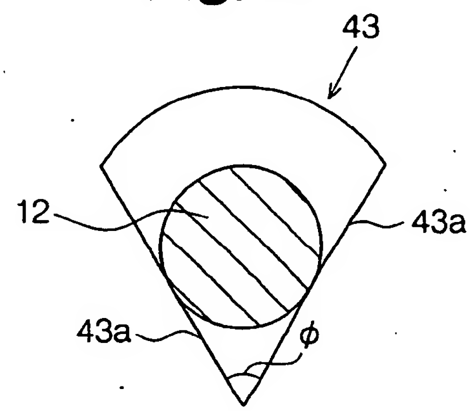


Fig.24

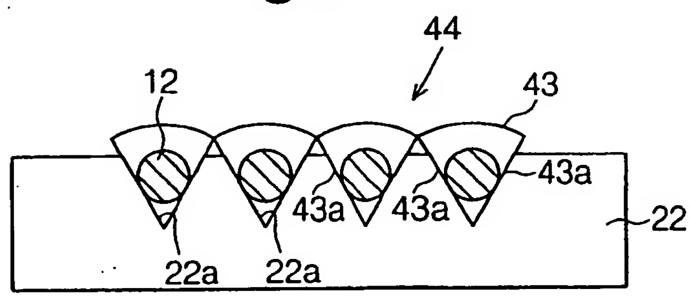


Fig.25

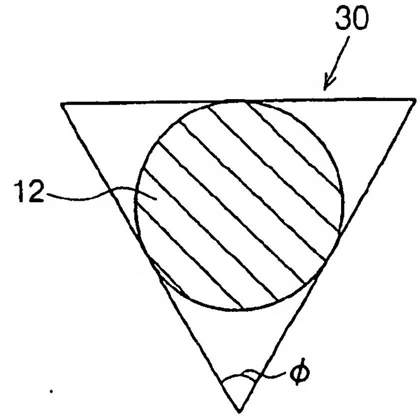


Fig.26

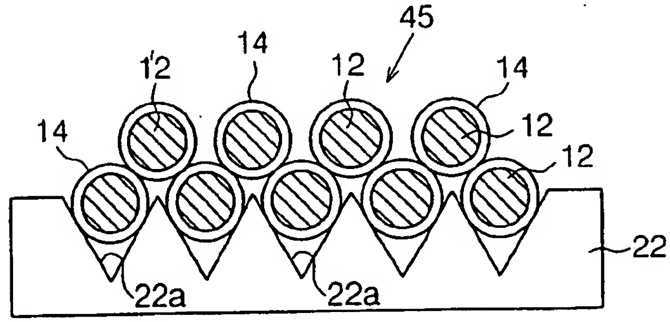


Fig.27

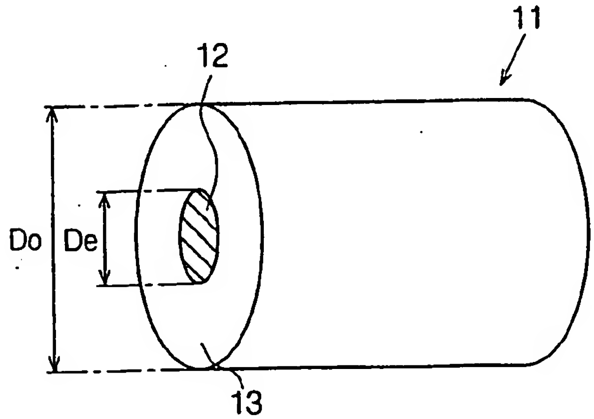


Fig.28

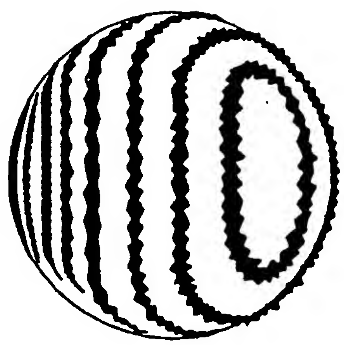
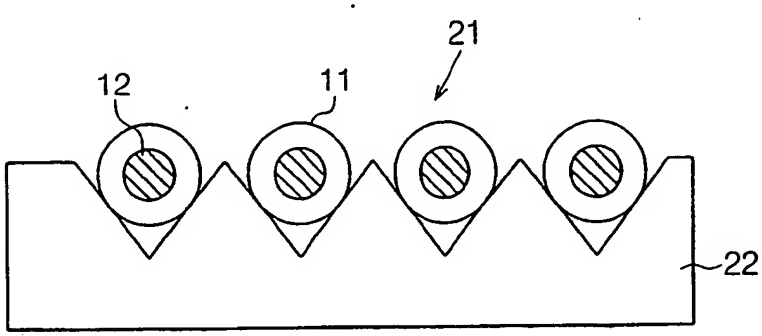


Fig.29



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EUROPEAN SEARCH REPORT

Application Number
EP 01 12 8733

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	US 6 088 166 A (LEE HO-SHANG) 11 July 2000 (2000-07-11)	1-4, 7-11,14, 15, 17-19, 21-23,26	G02B3/00
	* column 2, line 26 - line 65 * * column 3, line 12 - line 40; figures 1,3 *		
Y	* figure 1 *	20	
Y	US 5 923 481 A (FREITAS BARRY L ET AL) 13 July 1999 (1999-07-13) * column 5, line 23 - line 27; figures 4A,4C *	20	
X	US 4 789 219 A (LAYNE CLYDE B) 6 December 1988 (1988-12-06)	1,5,8, 12,14, 16,19,24	
	* column 4, line 29 - line 45 * * column 7, line 24 - line 38; figures 5,6 *		TECHNICAL FIELDS SEARCHED (Int.Cl.7)
X	PATENT ABSTRACTS OF JAPAN vol. 008, no. 075 (P-266), 7 April 1984 (1984-04-07) & JP 58 219507 A (NIHON ITA GLASS KK), 21 December 1983 (1983-12-21) * abstract *	1,2,4,6, 8,9,11, 13,14	G02B B29D
X	EP 0 918 235 A (NIPPON SHEET GLASS CO LTD) 26 May 1999 (1999-05-26)	1,8,16	
A	* paragraphs '0018!,'0039! *	2-7, 9-14,17, 21-25	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	11 March 2002	Besser, V

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A	PATENT ABSTRACTS OF JAPAN vol. 008, no. 129 (P-280), 15 June 1984 (1984-06-15) & JP 59 033415 A (NIHON ITA GLASS KK), 23 February 1984 (1984-02-23) * abstract * -----	1,3,4,6, 8,10,11, 13,14	
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The present search report has been drawn up for all claims

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